MULTI-SENSOR INSPECTION TELEROBOT

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ABSTRACT
This paper describes a telerobotic multi-sensor inspection system for space platforms developed at the Jet Propulsion Laboratory. A multi-sensor inspection end-effector incorporates cameras and lighting for visual inspection, as well as temperature and gas leak-detection sensors. A graphical user interface at the remotely located operator workstation provides utilities to plan telerobot inspection operations, display various sensor data, raise alarms, and catalog all data.

INTRODUCTION

NASA's planned Space Station will be used as a science platform for over thirty years. During this time, continuing damage from micro-meteorite impacts and atomic oxygen degradation can be expected [1]. Astronaut Extra Vehicular Activity (EVA) to perform routine and on-demand inspection for this damage, as well as inspection to support module checkout, /verification, could consume most of the EVA time available [3]. Telerobotic inspection is therefore an attractive alternative provided the technical feasibility of the approach is demonstrated. NASA has therefore sponsored the Remote *Surface inspection Task* (RSI), a five year technology demonstration task at the Jet Propulsion Laboratory (JPL).

The inspection system comprises of robot manipulator control, graphical user interfacing, and teleoperated/autom ated multi-sensor inspection [2]. The robot manipulator subsystem is comprised of a Robotics Research K 1207 arm mounted on a translating platform. The graphical user interface subsystem resides on a graphics workstation and provides user-friendly interfaces to the manipulator control and the inspection data. The multi-sensor inspection subsystem gathers and analyzes multi-sensor data from a realistic space station mockup under simulated orbital conditions.

INTEGRATED SENSOR END-EFFECTOR

A compact ($3.5kg$) *Integrated* Sensor *End-Effector* (ISEE) is shown in Fig. 1. The ISEE has the cameras and lights needed for visual inspection, as well as a suite of other sensors to detect temperature anomalies and gas leaks. The ISEE also has force and proximity sensors, as well as a gripper, but these are not directly used for inspection.

Temperature sensing is achieved with an infra-red optical pyrometer (8-12 micron wavelength), sensitive to temperatures from O to 1000°F. Gas sensing is achieved with

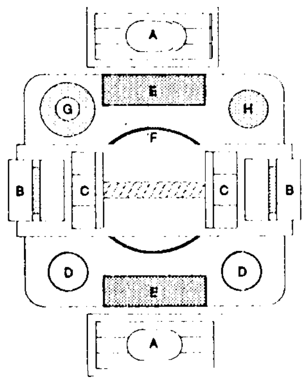

Figure 1: Front View of the ISEE: A - Two halogen lamps; B - Two strobe flash units; C - Parallel jaw gripper; D - Two **color cameras; E - Two infrared triangulation proximity sensors; F - A six DOF force/torque sensor; G - An optical pyrometer with laser sighting; H - A Metal Oxide Semiconductor (MOS) gas/vapor sensor**

a multi-gas Metal Oxide Semiconductor (MOS) type sensor which changes resistance as a vapor is absorbed (we recognize the superiority of a compact mass spectrometer in the ambient vacuum of space). The controlled lights are maintained at a known illumination level by a optics] transistor feedback circuit. This lighting is augmented by strobes that provide lighting comparable to solar illumination (when the cameras arc electronically shuttered to 1/1 0000 *sec*) but only for short, energy saving, single camera frame, bursts. Two Charge Coupled Device (C CD) color cameras are mounted in the ISEE and are suitable for human stereo- scopic viewing. The color images are displayed at the workstation, but the machine vision system only uses the luminance signal of the video signal (quantized to 8 bits).

MULTISENSOR INSPECTION

Consider the task of examining an Orbital Replacement Unit (ORU) for visual evidence of micro-meteorite impacts, temperature anomalies on fluid lines, and possible gas leaks from a stand-off (i.e non-contact) distance of approximately $0.5m$.

Inspection Scanning. The visual inspection actions requires a set of image frame-grabbing operations at a number of pre-selected "vista" points. Each vista point encompasses a comfortable portion of the ORU surface *area* with the field-of-view such that the camera system can resolve the visual flaws. Temperature anomalies are detected by the pyrometer which at the stand-off distance examines a spot corresponding to about $1cm$ x $1cm$. With this kind of instrument, it is not feasible to examine the entire surface area of the ORU laboriously. Instead, critical temperature locations (e.g. fluid valves, electrical junctions) are checked for anomalies by sensing along a *line* connecting the spots of interest. Gas leak detection requires that *volume* regions around the ORU be examined for the presence of leaking gases.

All of these multi-sensor elements can be exercised by an inspection scan path that traverses the ORU surface in a raster scan pattern (Fig.2). Scan paths are generated by a simple inspection planner (with human operator editing as desired) based upon knowledge of the geometry of the object., field-of-viclv of the cameras, sensor performance, and robot capabilities. The square symbols along the path denote vista points and the circular symbols denote temperature sensing points. The gas leak-detection is active at all times. If flaws are detected, the symbols or regions are colored red. A moving square (not shown in the figure) with a spatial extent corresponding to the field-of-view of the cameras is overlayed onto the scan path to indicate the current scan location. Real-time displays of sensor data is provided on moving bar graphs and audible/visual alarms.

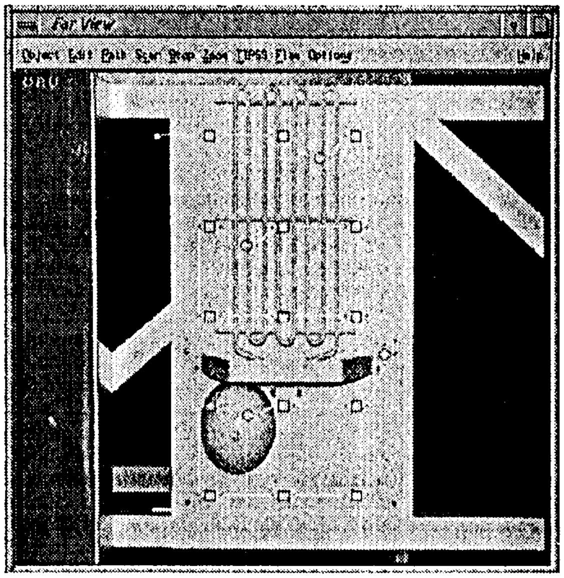

Figure 2: Inspection Scan **Path**

Flaw Archiving. The data obtained during the inspection as well as any operator annotations are cataloged into an archive for future examination and analysis in the form of an "image spreadsheet" (Fig. 3). The spreadsheet columns are indexed by the time of the inspection scan, and the rows arc indexed by different regions of the ORU surface. Selecting a set of the boxes calls up the image/sensor data for the corresponding time and regions as shown in the lower part of the figure. Selecting an entire column gives all inspection data for a given inspection time, and selecting a row shows the flaw history for a given region.

Visual Inspection. Visual inspection can be performed manually or by automatic means. In the manual mode the operator scans the images on a video-display as the scan-path is traversed by the robot. He thus has to focus only on the visual information and need not concern himself with the robot's motion. in the automated mode, the approach consists of locating and characterizing flaw-induced changes between an earlier *reference* image and a new ***inspection*** image. The reference data is obtained by running the inspection scan path in a mode where the object, visual appearance is baselined. Subsequent scans along the same path are used to obtain new inspection data for use in the comparison)] process. Simple differencing could be used to detect new damage if it were not for presence of noise, viewpoint differences, lighting variations, and benign changes. The solutions to these challenges to machine vision are described

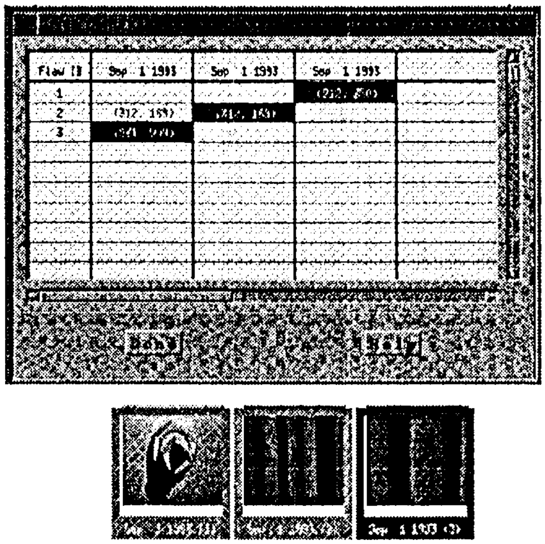

Figure 3: Flaw Spreadsheet and Image Data

elsewhere [4, 5].

CONCLUSIONS

We have briefly discussed the operation of a multi-sensor inspection telerobot. Performance characterization of the system and technology transfer to operational NASA space telerobots represent the next phase of activities.

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